TWO HIGH-PERFORMANCE MONOLITHIC MICROCIRCUITS FOR FM SOUND SYSTEMS

by David Bingham

SUMMARY

Microcircuits μA717 and μA718, with special adaptability to TV sound systems and FM applications, are described. Schematics of the RF and audio circuits and the device characteristics are discussed. Four consumer applications are given, including a table AM-FM radio, an FM-IF amplifier, a black and white solid-state television, and a color television receiver.

GENERAL DESCRIPTION

The μA717 and μA718 have been designed primarily for TV sound systems and general FM applications. The μA717 and the μA718 each contain two circuits. The first circuit functions as a high-gain amplifier with an optional built-in quadrature detector, which is useful in a TV receiver as a 4.5-MHz amplifier, limiter, and quadrature detector. The second circuit functions as an additional amplifier, with separate input and output terminals, designed to give sufficient power gain and power output to drive either transistor audio output stages (μA717) or tube audio output stages (μA718) of 0.5 watt to 2.0 watts. The audio drive requirements dictate the microcircuit supply voltage. The μA717 is designed to be operated with a +12 volt supply and typically can supply 20-mA peak-to-peak current at low source impedance to the audio output stage. The μA718 is designed to be operated with a +18 volt supply and typically can supply 16.5 volts peak-to-peak to drive a tube.

As shown in Fig. 1, the μA717 and the μA718 can be considered a set of building blocks when used in a TV sound system. The RF section consists of an amplifier (or limiter at high-input-level signals) and a current mode limiter which then feeds internally into an "OR" gate directly and also via

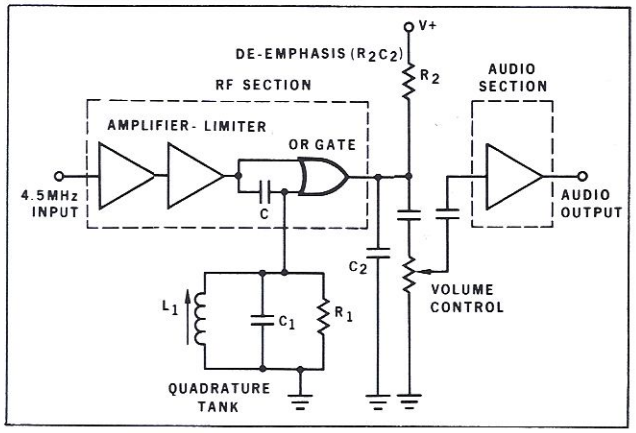

Fig. 1. TV sound system using μA717 and μA718 as building blocks.

a quadrature circuit consisting of C_1, L_1, and R_1, with L_1C_1 resonant at the input signal frequency (4.5 MHz for TV sound systems). R_1, L_1, and C_1 are components external to the microcircuit. The recovered audio signal is produced across R_2 and C_2. R_2 and C_2 also act as the de-emphasis network. The audio signal is then fed into a volume control and back into the audio section of the microcircuit where it is amplified, then coupled out again to drive the audio output stage. Complete schematics for the μA717 and μA718 are shown in Figs. 17 and 18.

RF Sections of μA717 and μA718

Fig. 2 shows the schematic for the RF sections of the μA717 and the μA718. The only difference is the value of R_2 in the bias chain (R_2 and R_3). This value determines the

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collector currents in all the transistors. To limit the power dissipation of the μA718, the value of R_2 has been chosen so that the collector currents in Q_1, Q_2, and Q_4 through Q_8 are the same as the corresponding currents in the μA717. The RF performance is approximately the same for the μA717 as for the μA718.

The input signal is fed into Q_1 through a circuit which provides a low impedance path between high and low inputs, (transformer winding, choke, or RC network with R<2 kilohms). Q_1 and Q_2 are an emitter-coupled pair with equal collector currents. These collector currents are established by the bias chain, R_2 and R_3, and the total resistance in the emitters of Q_1 and Q_2 -- between 325 and 350 ohms. Q_3 will be saturated since it has a saturation resistance of between 25 and 50 ohms. (Note: Q_3 plays no active part in the operation of the μA717 and μA718.)

The output signal of the first stage is developed across R_6 and coupled into the following amplifier-limiter (Q_4 and Q_5) by C_1. Essentially, the mode of the second-stage operation is identical to the first stage. The bias network, R_2 and R_3, is common to all the RF sections. The output signal is taken at the collector, Q_5.

The third stage is unique in that it can be used either as an amplifier or as a quadrature detector.

As an amplifier, the QUAD terminal can either be left open or may be connected to ground. In both cases, the dc voltage on the base of Q_7 will be zero. Therefore, the collector current that flows in Q_7 is zero; and C_3, R_{11}, and Q_7, may be ignored. The third stage, then, reduces to an emitter-coupled amplifier-limiter (Q_6 and Q_8) with the input signal coupled in via C_2 (20 pF) and resistor R_{12} (2.5kΩ). The output signal may be taken from the RF output terminal and, depending on the application, may drive a ratio detector, a discriminator, or any other desired circuit. However, for most applications, the use of a ratio detector or discriminator could not be justified from either an economic or performance point of view for reasons given later. (The only exception is the case where an AFC signal is required.) The voltage gain of the complete RF section with a 1-kΩ resistive termination is shown in Fig. 3.

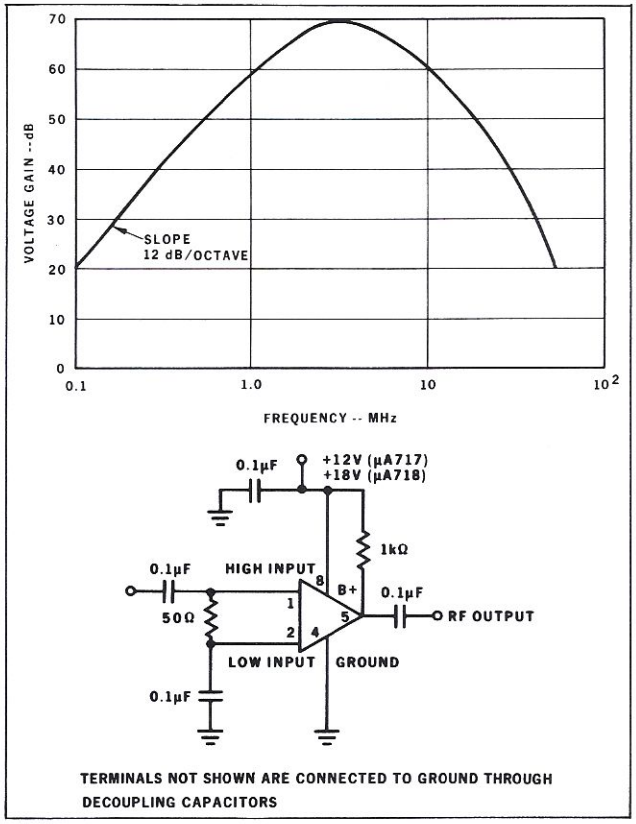

Fig. 3. The μA717 and μA718 voltage gain.

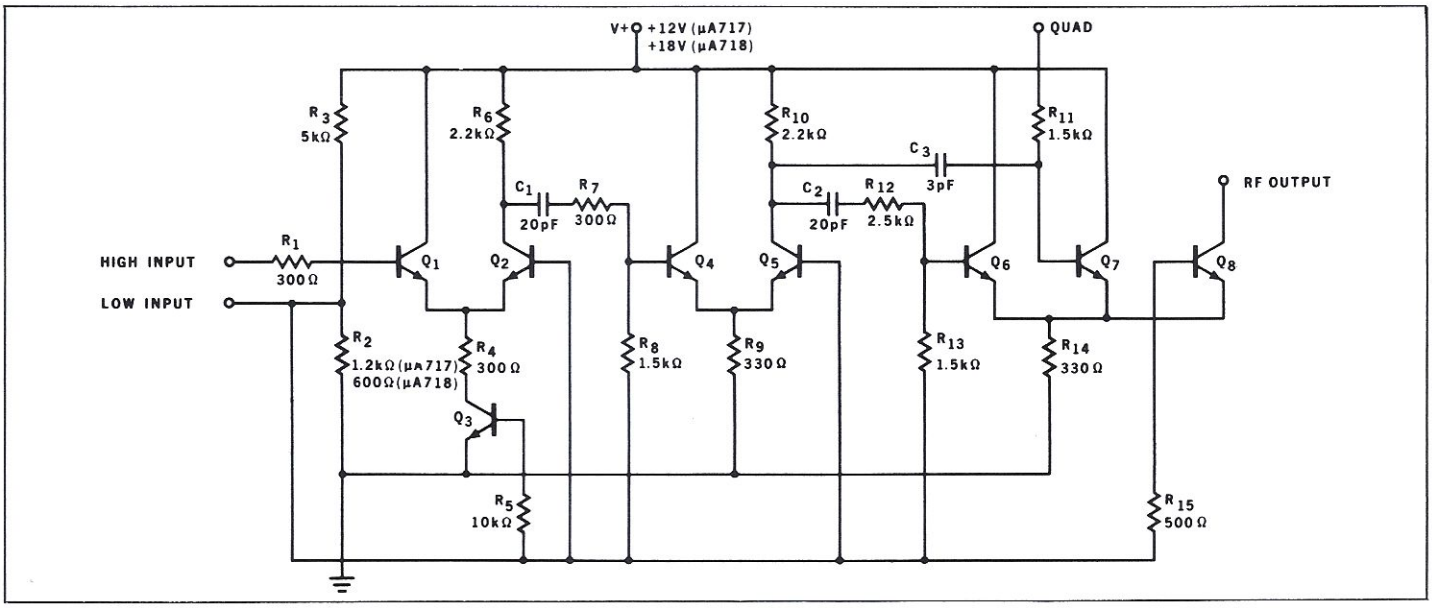

Fig. 2. Schematic of μA717 and μA718 RF sections.

The circuit has been designed for maximum RF gain at 4.5 MHz and the values of coupling capacitors C_1 and C_2 are chosen accordingly. As can be seen in Fig. 3, the gain falls off at 12 decibels per octave at low frequencies, and a little more steeply at frequencies above 20 MHz. The useful frequency range is between 100 kHz and 50 MHz.

The frequency above which the RF stages current mode limit is 2 MHz for the μA717. The μA718 current mode limits at all frequencies. (Current mode operation gives symmetrical limiting without phase distortion of the FM signal. This improves the AM rejection, capture ratio, and the distortion of the demodulated audio signal).

High values of power gain (of the order of 70 dB) can be realized at 4.5 MHz in practical circuits, with input and output matching. The reverse transfer admittance (feedback capacitance, etc.) is extremely small and both microcircuits can be used to obtain gains approaching gain maximum available (GMA), (70 dB at 4.5 MHz) with no special precautions if the low input terminal is bypassed by a high-quality capacitor of 0.01 microfared or greater.

The Quadrature Detector

Quadrature detectors have been used for many years with vacuum tubes as TV sound detectors. This has been possible because multigrid tubes offer several control electrodes, with good isolation between each electrode. The major advantage of the quadrature detector has been in cost/performance considerations, especially in the simplicity of the design of the quadrature tank circuit. Discriminators, ratio detectors, etc., involve complex and expensive transformers of two poles and require more difficult tuning procedures than those for a simple quadrature detector.

One of the well-known advantages of silicon monolithic linear integrated circuits is the low cost of matched transistors and resistors. This has allowed a complete re-examination of the FM detector circuit based on a different cost criteria than that of a discrete component system.

One solution to the FM detector can be found in the OR gate used in current-mode logic circuitry.

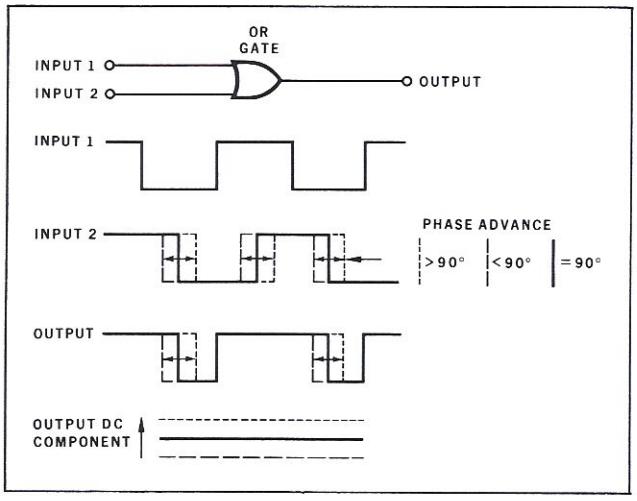

Fig. 4. OR gate.

The logic functions are shown in Table I. Consider the case where one of the input signals (INPUT 2) is displaced with respect to the other input signal in phase by 90 degrees. The conduction period on the low output will be one-quarter of the total duty cycle. If the phase of INPUT 2 signal is varied about 90 degrees, the low output period will vary in the same manner. The output signal is integrated to remove the AC components resulting in a dc level. This is illustrated in Fig. 5, where the phase difference between the two input signals is plotted against the dc component of the output signal.

TABLE I.
Output Voltage for Various Combinations of Input Voltages.

INPUT 1	INPUT 2	OUTPUT
High	Low	High
Low	High	High
High	High	High
Low	Low	Low

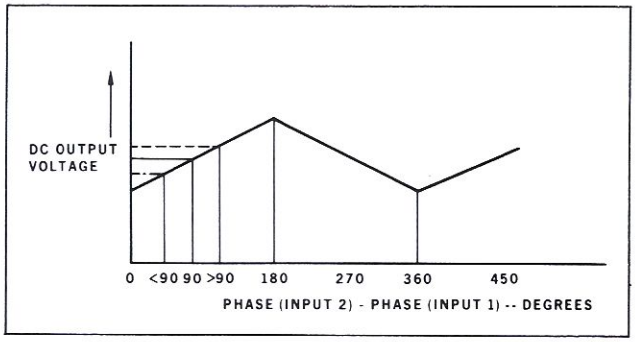

Fig. 5. OR gate input-output characteristics.

In the theoretical case, perfect linearity can be achieved; in a practical case, good linearity can also be achieved, as will be shown.

The practical OR gate configuration chosen for the μA717-μA718 is the emitter-coupled trio of transistors, with the two input signals applied to the bases of two of the transistors, Q_6 and Q_7, and the resultant output signal taken from the collector of Q_8. In this way the OR gate can be conveniently converted into a straight emitter coupled amplifier (previously described) without additional external components.

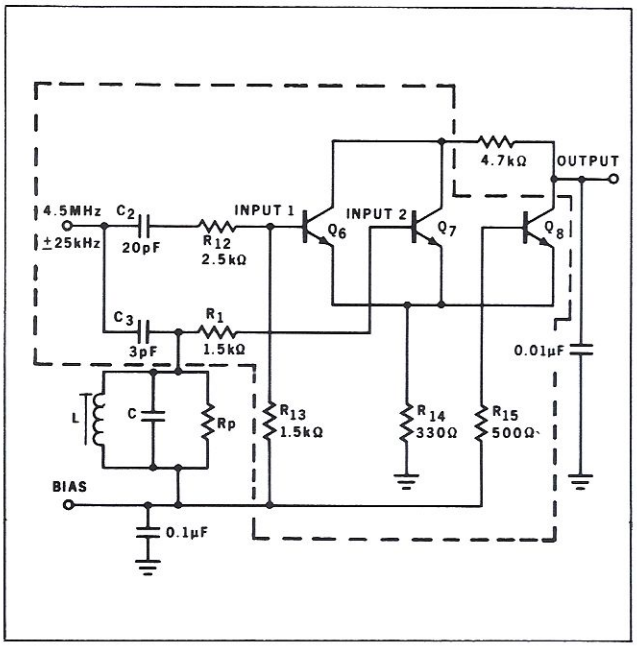

Fig. 6. The μA717-μA718 quadrature detector.

The complete quadrature detector is shown in Fig. 6. The 90-degree phase shift for one input is achieved primarily by C_3 (3 pF) and the R_P of the quadrature coil. The other input signal is fed into the base of Q_6 via C_2 (20 pF) and R_{12} (2.5 kΩ). Resistor R_{12} serves to isolate the common input drive point from Q_6. The output signal is integrated by a 4.7-kΩ resistor and 0.01-μF capacitor to obtain the audio component. (De-emphasis is achieved at the same time with suitable component values.)

The phase-frequency relationship of a tuned circuit very near to or at resonance approaches a linear function for small frequency deviations. Therefore, a practical design for either TV sound (4.5 MHz) or FM broadcast (10.7 MHz) IF system requires suitable compromises between the Q factor of the tuned circuit, the amplitude of the recovered audio output signal, and the audio distortion. Q factors in the range of 30 to 60 are required for TV sound systems (±25 kHz deviation). For FM applications at 10.7 MHz, lower Q factors should be used to obtain linearities of better than 1.0 percent for ±75 kHz deviation.

Another way to improve detector linearity is to use a double tuned quadrature coil. The phase-frequency linearity of a double pole filter is optimized by choosing kQpr = 0.7, where k is the coupling factor and Qpr is the quality factor of one pole of the filter. The major advantage of the two-pole filter is higher detector sensitivity for a given linearity, as compared with a simple quadrature coil. The quadrature tank circuit is shown in Fig. 7. This circuit results in linearities as good as the best ratio detectors and discriminators, and should prove to be popular in high-quality FM tuners.

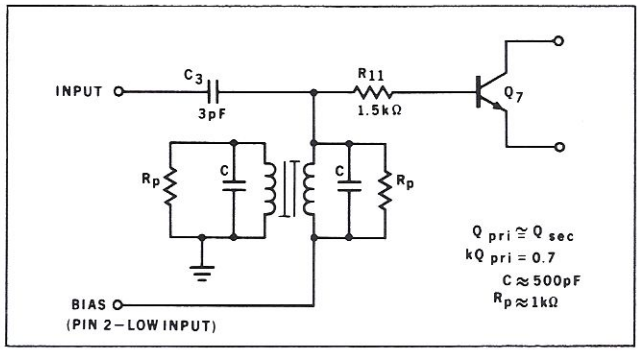

Fig. 7. Double tuned quadrature detector.

The input conductance and capacitance of an emitter-coupled transistor configuration varies as a function of the applied input signal level (see Fig. 8.). It is seen that the input conductance and capacitance decrease with increasing signal.

The value of the tuning capacitor and the Q factor of the quadrature tank circuit should therefore be chosen so that input variations of transistor Q_7 with the normal range of values of the input signal will not appreciably change the Q or resonant frequency of the tank circuit. It has been found that a tuning capacitance of about 500 picofarads is optimum for both 4.5-MHz and 10.7-MHz operation.

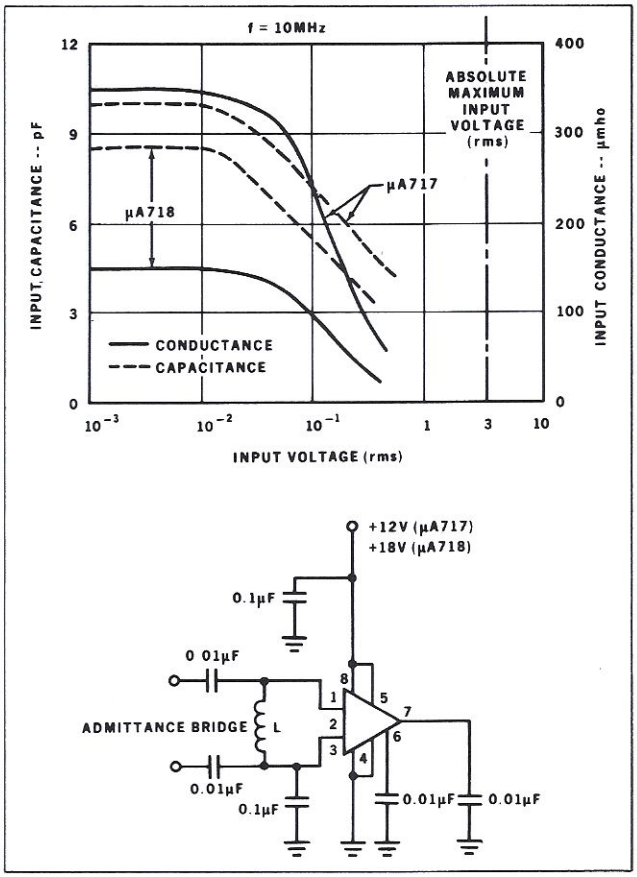

Fig. 8. Input capacitance and conductance as a function of the input signal level for an emitter-coupled pair.

AUDIO SECTIONS

The audio drive requirements for tubes and transistors differ considerably and are responsible for the different supply voltages of the two devices, μA717 and μA718. The μA717, designed to drive transistor output stages in both color and black-and-white TV receivers, will be described first.

μA717 Audio Section

There are various supply voltages from which audio output stages are operated. However, they can be classified into two principal ranges; namely, high voltage (150 volts) and low voltage (12 to 36 volts). The audio section of the μA717 has been designed to operate in both ranges. Fig. 9 shows the schematic of the audio section of the μA717.

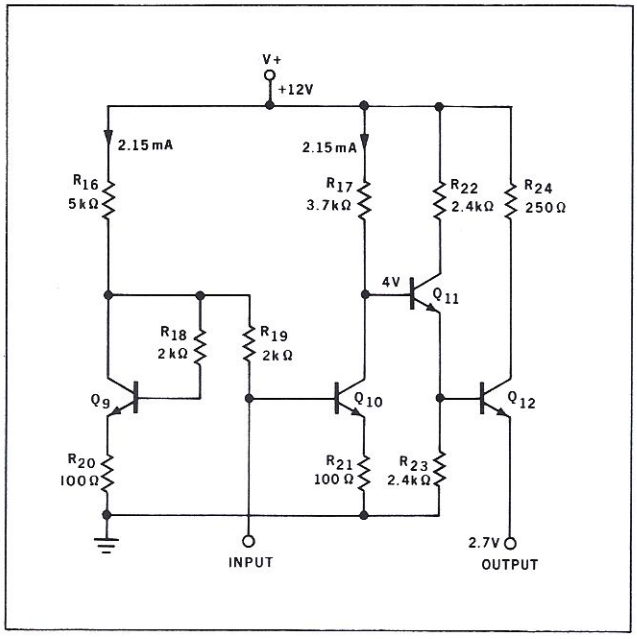

Fig. 9. Audio section of the μA717.

The bias of the audio amplifier is established by the supply voltage and the components Q_9, R_{16}, R_{18}, R_{20}, which sets up a current in Q_9

$$I_{Q_9} = \frac{\left(V_{supply} - V_{BEQ_9} - I_{BQ_9} R_{18} \right)}{\left(R_{16} + R_{20} \right)} ,$$

or approximately 2.15 milliamperes.

Q_9 and Q_{10}, R_{18} and R_{19}, and R_{20} and R_{21} are matched pairs of components. Therefore, the collector current of Q_{10} is the same as that of Q_9; i.e., 2.15 millamperes. The collector voltage of Q_{10} is 4.0 volts. Two V_{BE} drops of Q_{11} and Q_{12} give a resultant dc output voltage of 2.7 volts for the audio output terminal. Due to closely matched components, this output voltage can be held accurately in production.

Q_{12} can drive directly into an output transistor. As such, the positive and negative excursions of the output drive should be similar (i.e. approximately ±3 volts dc), otherwise it is possible for the mean dc bias of the power output transistor to change under overdrive conditions and, under extreme conditions, to destroy the output transistor. To avoid peak positive output voltages greater than 6 volts from the microcircuit, Q_{11}, R_{22}, and R_{23} have been included. The emitter follower, Q_{12}, can supply peak currents of 20 milliamperes, this current being limited by the saturation voltage of Q_{12} and the output short-circuit protection provided by R_{24}.

Fig. 10 shows the recommended schemes for driving high-and low-voltage audio output stages with the μA717. The high-voltage scheme permits the most economical operation and can provide two watts of power to the loudspeaker. The low voltage scheme employs a dc feedback circuit to re-establish the output dc voltage from the microcircuit, allowing more of the supply voltage to be used to provide audio power with less voltage across the emitter resistor of the output transistor.

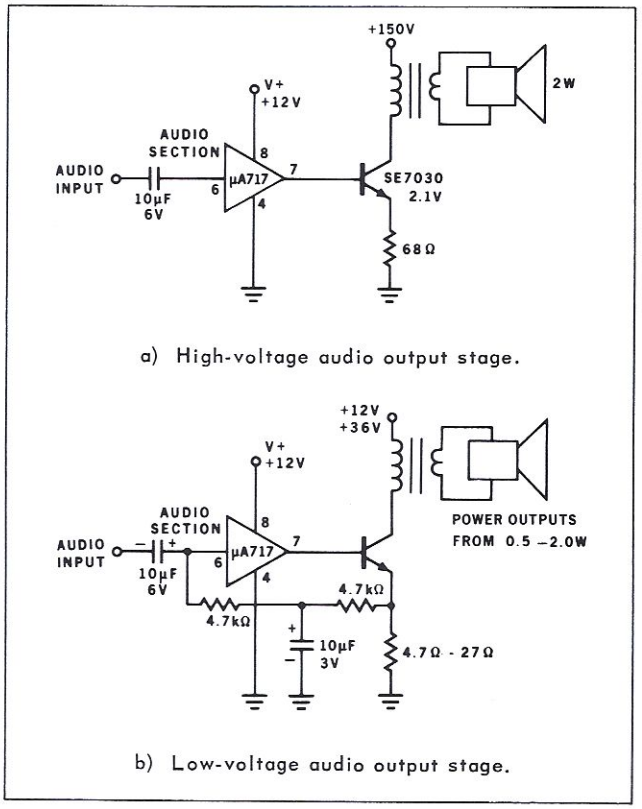

Fig. 10. Typical audio configurations for the μA717.

μA718 Audio Section

The audio section of the μA718 has been designed to drive a tube audio output stage in a hybrid TV receiver. More than 15 volts peak-to-peak drive is required for most tubes. Therefore, an 18-volt supply is employed for the μA718 to obtain necessary audio voltage drive.

By means of a simple metal mask option on the basic μA717 circuit, the audio section (Fig. 11) for the μA718 is obtained.

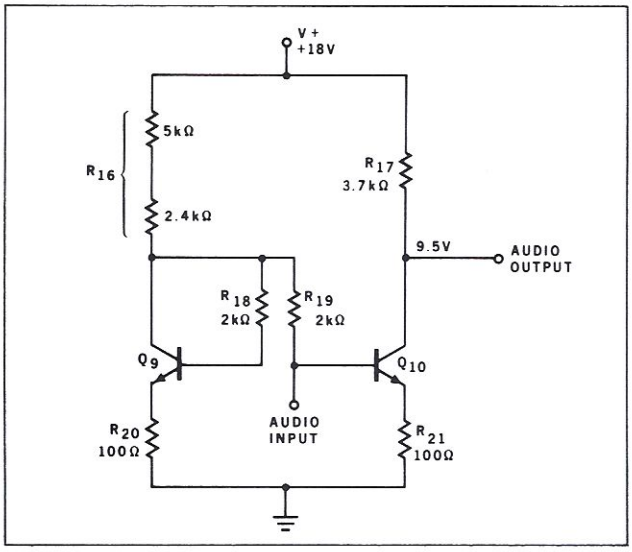

Fig. 11. Audio section of the μA718.

Since R_{17} is equal to one-half of R_{16}, and the rest of the circuit is symmetrical, the bias of the audio output terminal is approximately equal to one-half the supply voltage. A little over 16 volts peak-to-peak audio swing is obtained. A typical tube output circuit is shown in Fig. 12.

The audio section of the μA718 may also be used as an additional IF amplifier, featuring well-defined input and output impedance and gain. It is recommended that the audio section be used as an IF amplifier following the RF section, due to the pin configuration and the instability problems with very high gain. This application gives the μA718 the highest overall RF gain of any linear integrated circuit obtainable today.

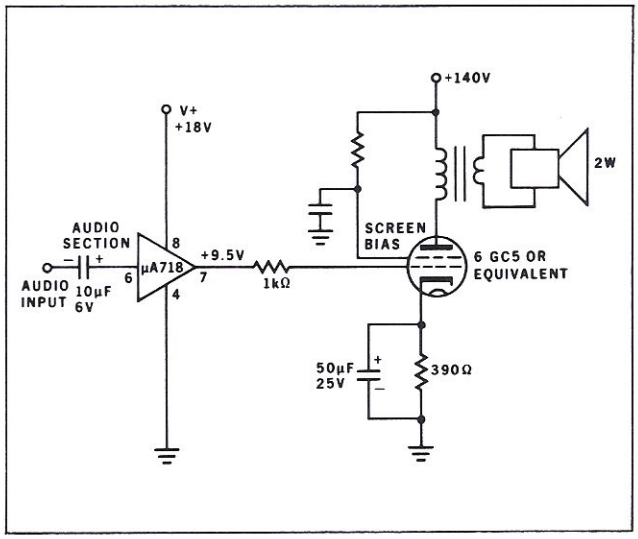

Fig. 12. The μA718 driving a tube output.

APPLICATIONS

Typical consumer applications for the μA717-μA718 are shown in the circuits of Fig. 13 through Fig. 16.

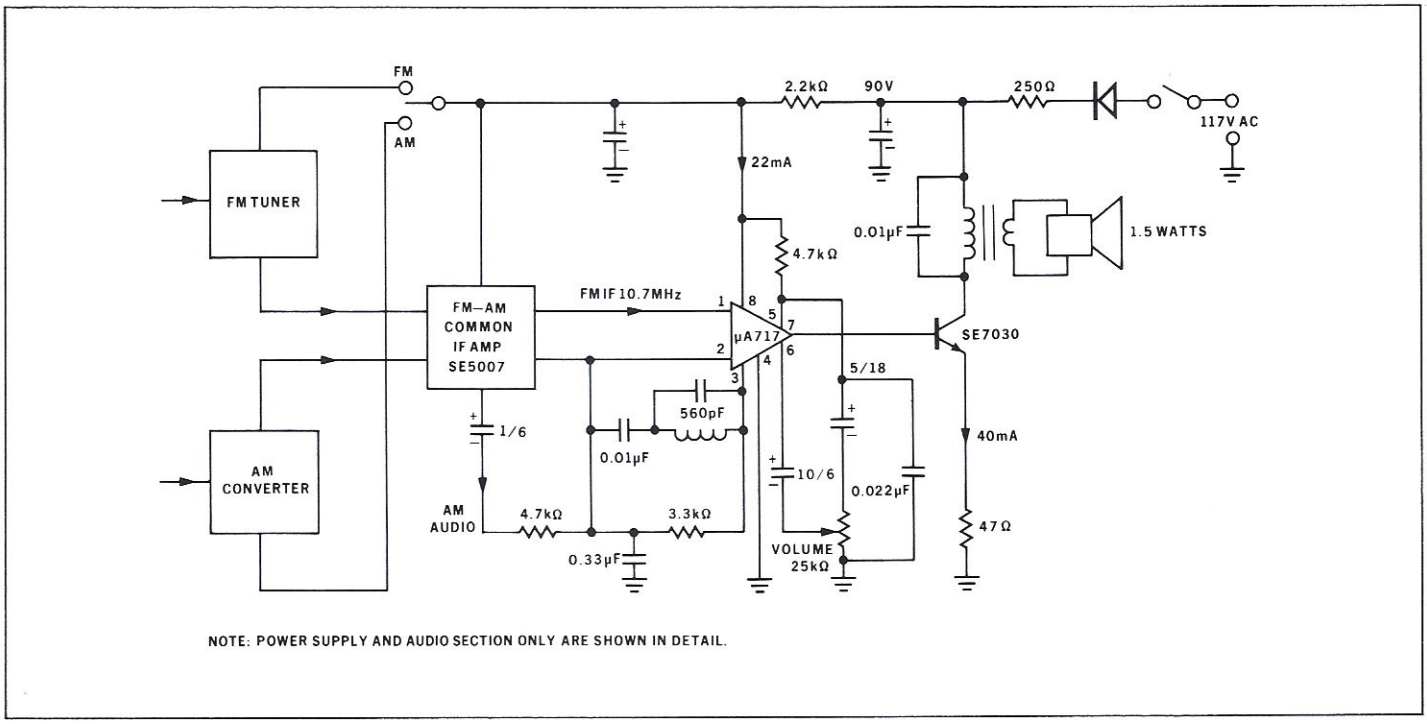

Fig. 13. Table AM-FM radio.

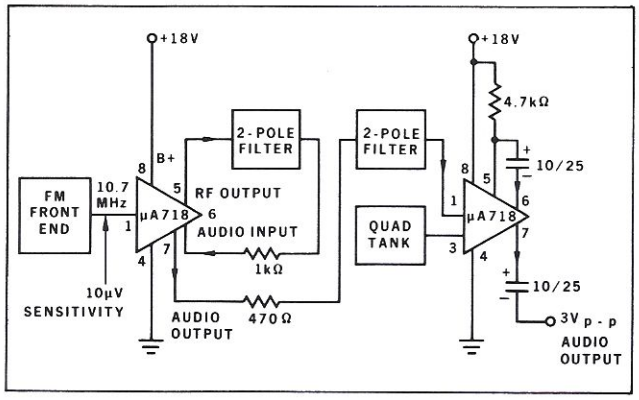

Fig. 14. High-quality FM-IF amplifier.

In the FM-IF amplifier above, the audio section of the first μA718 is used as an additional 10.7-MHz amplifier.

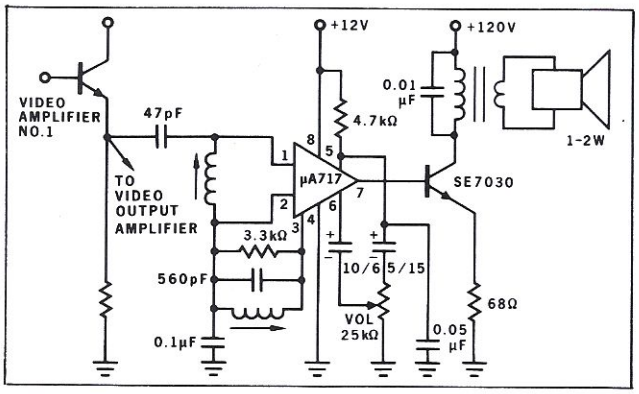

Fig. 15. Black-and-white solid-state TV sound IF system.

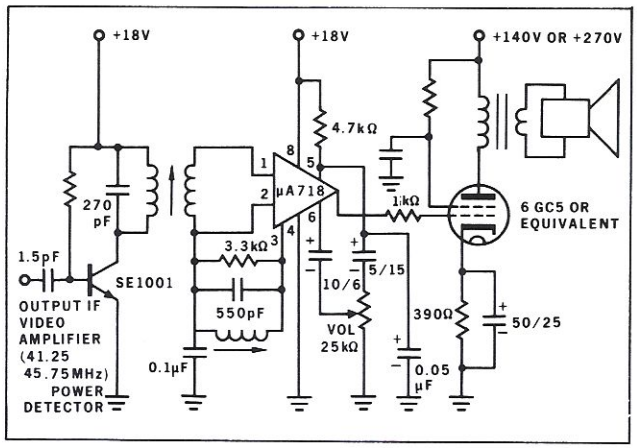

Fig. 16. Color TV receiver sound IF system.

CONCLUSION

The μA717 and μA718 linear microcircuits have been described in detail and performance data given. By the use of four typical applications it has been demonstrated that the μA717 and μA718 can be used to advantage in most consumer FM systems. Component count and circuit complexity have been reduced compared with previous designs.

The μA717 and μA718 provide the design engineer with flexibility and optimum performance, at costs lower than equivalent discrete transistor or vacuum tube approaches.

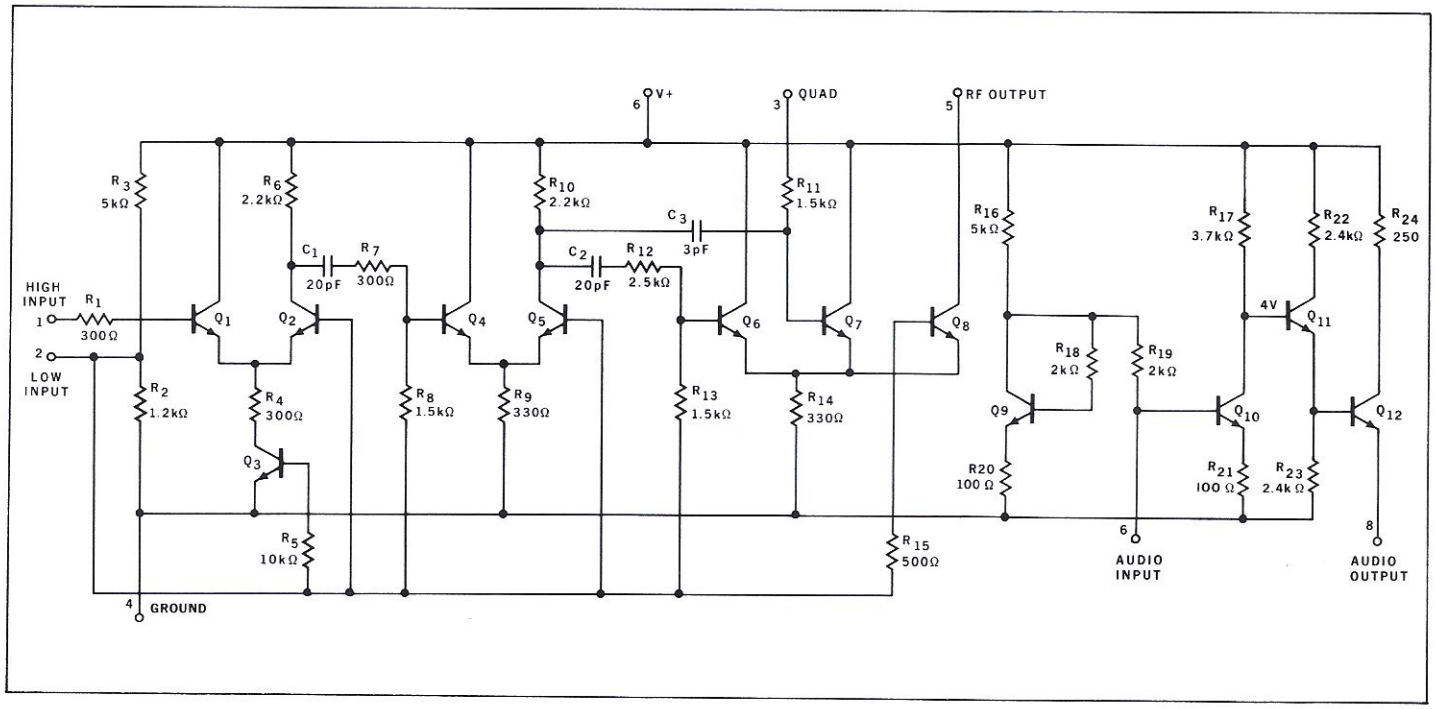

Fig. 17. Schematic of the μA717.

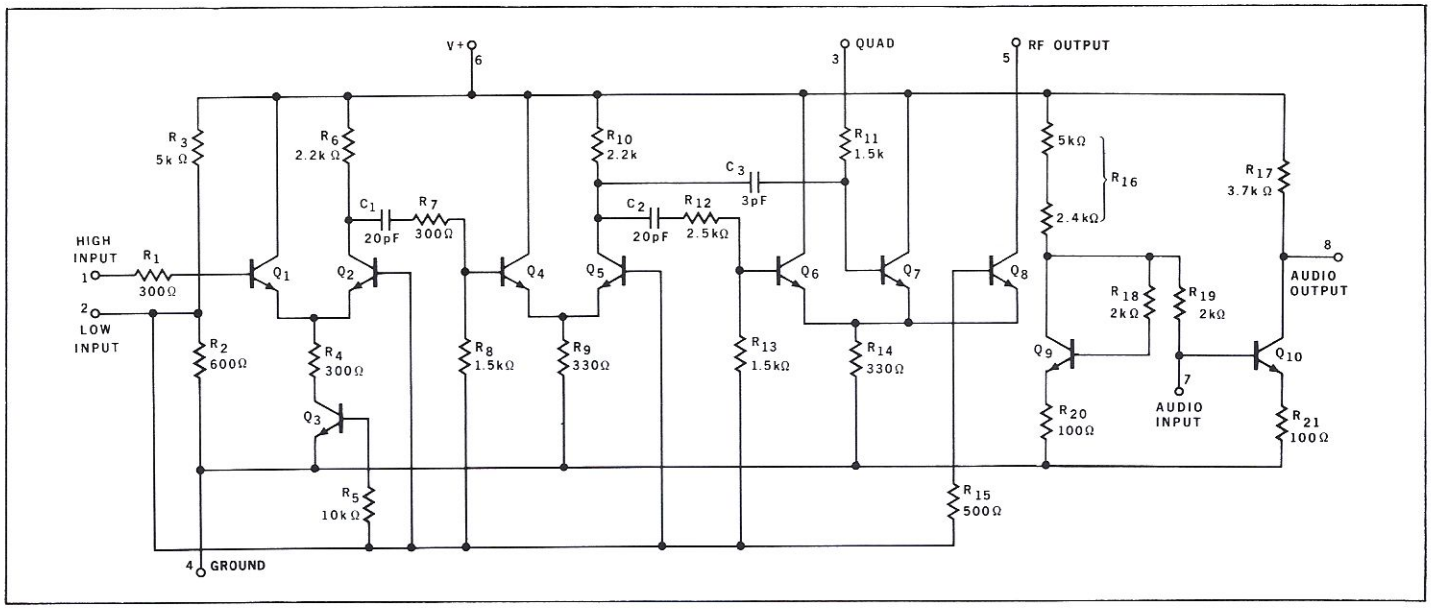

Fig. 18. Schematic of the μA718.